NMC-662

E7.3 109.0.8.

CR-133565

ENGINEERING ANALYSIS OF ERTS DATA FOR

RICE IN THE PHILIPPINES

Howard L. Heydt, General Electric Company
General Electric Valley Forge Space Center
Pennsylvania 19101

Arthur J. McNair, Cornell University
Ithaca, New York 14850

BIOGRAPHICAL SKETCHES

Howard L. Heydt, Consulting Engineer - Remote Sensing at the General
Electric Valley Forge Space Center, Pennsylvania, received the BS and
MS in Electrical Engineering from M.I.T. Following periods as
development engineer, U.S. Army Security Agency, and Instructor/Asst.
Professor of Electrical Engineering, University of Connecticut,
Heydt joined the General Electric Company, serving as project
engineer, manager and consulting engineer. He has been concerned
with remote sensing since 1962, including development of airborne TV
and IR sensors and of multispectral image analysis equipment, and for
many years the actual imagery analyst for a variety of
environmental/natural resource management applications. Heydt is a
senior member of the I.E.E.E.

Arthur J. McNair is Professor of Civil and Environmental Engineering
at Cornell University where he teaches and performs research in
Geodetic and Photogrammetric Engineering and Remote Sensing. He
received his BS(CE), MS and CE degrees from the University of
Colorado where he taught before moving to Cornell. He is a past
president of the American Society of Photogrammetry. He is also a
past officer of ASEE, ASCE, AAAS, and ACSM and a member of Canadian
Institute of Surveying and Sigma Xi. In 1970 Prof. McNair performed
a digitized/computerized inventory of some 200 types of land use and
natural resources of the 100,000 square miles of the State of
Colorado. He is a member of the Parent Committee and past chairman
of the Cartography Panel of the Committee on Remote Sensing Programs
for Earth Resources Surveys of the National Academy of Sciences.

ABSTRACT

Rice is an important food world-wide. Worthwhile goals, particularly
for developing nations, are the capability to recognize from satellite
imagery (1) areas where rice is grown and (2) growth status (irrigation,
vigor, yield). A two-step procedure to achieve this is being investi-
gated. Ground truth, and ERTS imagery (four passes) covering 80
percent of a rice growth cycle for some Philippine sites, have been
analyzed. 1-D and 3-D signature extraction, and synthesis of an initial
site recognition/status algorithm have been performed. Results are
encouraging, but additional passes and sites must be analyzed. Good
position information for extracted data is a must.

## INTRODUCTION

The world-wide importance of rice as a food is generally known. The investigation reported here has been focused on the rice planting-growth-harvest cycles in the Philippines through the analysis of ERTS image data. Much of what will have been learned at the completion of this program will be applicable, it is felt, to rice production elsewhere in Southeast Asia, and also applicable to other agriculture in those areas. Two principal objectives of the investigation are (1) to establish the feasibility of extracting from ERTS imagery the areas where rice is grown, and (2) to determine those measurements on the imagery, and the effectiveness of the measurements, which enable the assessment of crop status (moisture, vigor, maturity, harvesting, etc.). Achieving these objectives with procedures which are cost-effective can lead the way toward improved yield prediction, irrigation system management and similar functions which are known to be important needs in Southeast Asia. Even a moderately accurate inventory of the total area in which rice is grown, as determined from analysis of ERTS image data, would be of considerable value, we are told.

In order to achieve the objectives of this investigation, it is our plan to extract reliable spectral signatures from image data for the test site areas, carefully correlate signatures with ground truth, and use the correlation results to develop recognition algorithms. Two degrees of recognition are planned:

(1) Recognition of the areas (throughout the Philippines) where rice is grown

(2) Assessment of rice crop or site conditions.

It is felt that the two-part recognition process is necessary since rice field conditions are so varied at any given time that signatures of large rice areas will be a composite of many signatures some of which could also be found in non-rice areas - thus creating an error problem if a particular spectral signature recognition process is used generally. Alternatively, to exploit the spectral signatures of the myriad of individual rice field conditions would seem to be an overwhelming task. But, if it can be established first that an area under analysis in the imagery is definitely a rice field (and this is being done through the use of the temporal variations in the signature), then it should be possible to extract site status information from the signatures with a minimum of confusion with signatures pertaining to non-rice areas.

It was decided to work initially with image data in transparency form -- color composites and black-and-white single-band imagery. Eventually, the procedures developed will be performed using image data primarily in digital tape form. But because of the complex and difficult-to-recognize nature of the test sites (described in the section which follows), transparencies have been used initially. To analyze the transparencies, the General Electric Multispectral Image Extraction Systems (GEMS) is used. GEMS is a unique and flexible hybrid analog-digital system for use in imagery analysis for a variety of applications. It involves near-real-time scanning of the imagery using a 3-channel TV sensor, and includes a variety of electronic

processing and display functions.  Importantly, GEMS is tied to a
digital computer.  System operation can range from essentially automatic
to an aided-manual mode, and such operation is under the control of the
operator/analyst who observes the system displays and outputs, makes
judgments, and communicates with the system via a control panel and
keyboard.

Test site areas where adequate ground truth data are maintained exist
in several locations in the Philippines.  To date we have confined our
analyses to two such areas (several sites within each area) simply to
become familiar with the situation at a single location before broad-
ening the scope of the analysis.  Also, the ERTS imagery available
covers this selected area more extensively than other site areas.

Finally, it is noted that the investigation is a joint effort of
Cornell University and the General Electric Company, with key parti-
cipation also by the University of the Philippines at Los Baños, and
by the International Rice Research Institute.  The investigation is
supported by the National Aeronautics and Space Administration under
contract NAS 5-21844 with Cornell University, and is identified as
ERTS Data Application Project U-160.

## LOCATING THE SITES IN THE IMAGERY

Figure 1 shows the type of rice region scene with which we are
concerned.  The figure is a photograph of the GEMS color TV monitor
display of an optically zoomed portion of an ERTS color composite
transparency.  The field-of-view shown, about 7 NM. x 7 NM., is that
at which we usually conduct our analyses.  The particular scene
shown in the figure is near Gapan, about 50 miles north of Manila on
the island of Luzon.  A considerable number of rice fields exist in
the region shown in the figure.  However, the sites where ground
truth is available number about a dozen, and these vary in size from
10 hectares (1000 ft. x 1000 ft.) to 260 hectares (4000 ft. x 7000
ft.).  The site areas involve from 12 to 350 ERTS resolution cells.
Most important, the sites usually appear to be spectrally non-
homogeneous for much of the growth cycle.  These conditions make it
virtually impossible to recognize a test site by its spatial
properties.  The site can only be located by triangulation from
recognizable reference points in the scene, and these occur
infrequently.

For geometric reference points in the Gapan region we have chosen
three river bends (the same river as in the upper left of the figure)
which are just out of the scene shown in the figure.  From maps of the
area on which the test site boundaries have been marked by the ground
truth team, X (East-West) and Y (North-South) distances to the river
bend reference points have been determined.  These distances have then
been scaled for a photograph similar to that shown in Figure 1, and
pin-holes placed in the photograph at the centroid of each site.
Finally, using a similar scaling process, the site boundaries were
drawn on the photograph around each pin-hole.
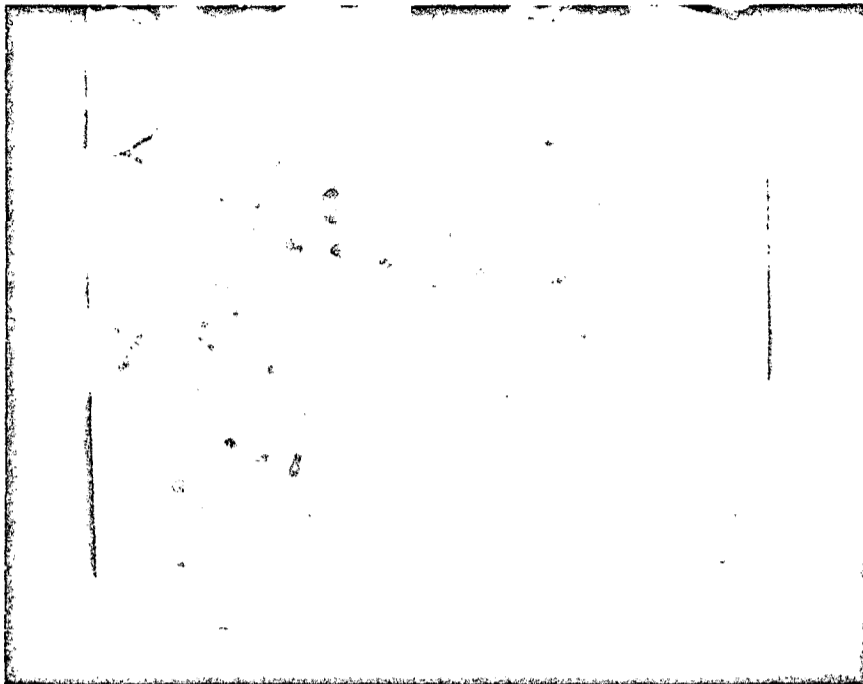
|◄─────── 40,000 Ft. (Approx.) ───────►|

FIGURE 1. Some Philippine Rice Fields as
Displayed by a Color TV Scan of a Portion of an
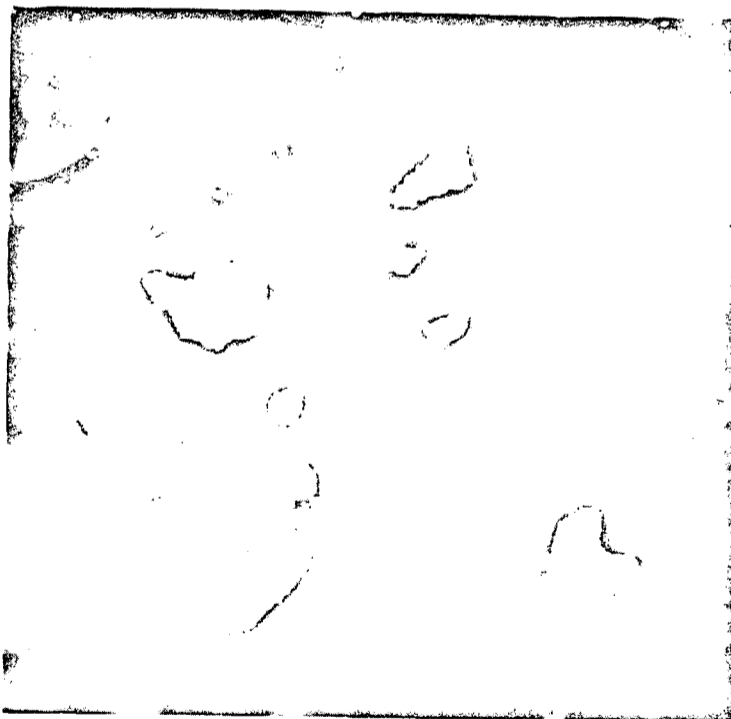ERTS Composite Transparency



FIGURE 2. Synthesized Electronic Binary Site
Map Superposed on TV Display of the Scene

It was then decided to reproduce electronically in the GEMS the site boundaries and the area contained within these boundaries. This was performed by manually entering binary data into the appropriate individual elements of a 500 x 500 core-storage array. The results are superposed at the analyst's discretion on the TV display of the scene, and he continues to modify the stored binary data until the result conforms satisfactorily to the site boundary locations as drawn on the photograph. The resulting synthesized binary site map, superposed on a display of the scene, is presented in Figure 2. The procedure, of course, is not exact, but it is felt that the boundaries are now within two or three ERTS resolution cells of where they should be. For small sites, any greater deviation could seriously affect the usefulness of extracted signatures, particularly if rice field conditions are different outside the site boundary from conditions within.

There are two important desirable aspects of the binary site map. First, if new information indicates a boundary should be adjusted, it is a relatively simple matter to update the stored data. Second, once prepared, the binary site map is easy to use. It is stored on digital tape and recalled when desired. It has been used with both color composite transparencies and single-band black-and-white transparencies for ERTS imagery obtained on different days. Once the binary site map is recalled from store and superposed on the display of the scene, it is a comparatively easy task to register the two. Registration marks have been included in the stored binary map along the two rivers and their confluence in the upper left of the scene in Figure 2. (Those rivers, incidentally, appear to be the only useful geometric references). To facilitate the registration, there are GEMS controls for translation and orientation of the displayed scene, and a control for the scene magnification if a minor scale change should be necessary.

## 1-D SITE SPECTRAL SIGNATURE EXTRACTION

Imagery in the form of MSS single-spectral-band positive black-and-white transparencies which were available as of July 1973, and in which test sites of interest were not cloud-covered, included ERTS 1 passes on the 100th, 118th, 153rd and 189th days in orbit. Dates for these passes are, respectively, 31 October, 18 November, and 23 December, 1972, and 28 January 1973. These passes cover a period of approximately 13 weeks and span the end of the wet season harvest (October-November), site preparation and planting (November-December), and 30-60% (December-January) of the rice growth in the dry season. Dry season harvest for these sites occurred mostly in March and April.

Seven sites were studied - three IRRI* barrios near Gapan, and four Peñaranda River Irrigation System (PRIS) barrios monitored by the University of the Philippines at Los Baños (UPLB). The UPLB sites are near Gapan also and can be observed in the same frame as the IRRI sites. Ideally, each of the seven sites is to be examined for the four passes and for the four MSS bands - 4, 5, 6 and 7. About 75% of these cases were analyzed by 15 August 1973.

* International Rice Research Institute.

4

As noted previously, each of the sites is relatively small**, difficult
to locate accurately in the imagery, and invariably non-homogeneous
spectrally. For these reasons, single-band (1-D) signatures were
extracted from the imagery which are composite signatures for each site
as a whole, rather than signatures for the different features within a
site. To do this, the binary site map was recalled from store in the
GEMS and registered visually with each black-and-white transparency.
Next, a radiometric calibration was performed which related the 32
GEMS signal intensity levels (corresponding to transmission levels in
the transparency) with the 15 steps in the step wedge on each trans-
parency. Then, using the binary site map and the GEMS cursor, a 1-D
histogram signature was extracted for each site for each of the four
passes and usually for all four MSS bands. Each histogram is in
normalized form, showing the percent of total pixels in each site which
fall within each of the 32 GEMS intensity levels. Using the radio-
metric calibration data, each histogram then is converted to percent
site pixel population falling within each half-step of the 15-step
wedge. For each histogram, the bulk of the population occurred in two
to seven half-steps, although the specific half-steps involved were
often different for each case examined. Finally, for each histogram
the location was determined for the mean intensity value — expressed
as a point along the 15-step gray-wedge scale (e.g., step 13.2, step
9.8, etc.).

Results of the above analysis are presented in Figure 3. Mean intensity
is plotted as a function of time for each site and for each of the
four spectral bands. No variance data were included in the plots at
this time. A similar set of plots of 3-D signature information vs.
time is being prepared, but to date these include only two passes --
31 October and 18 November.

### COMPARISON OF 1-D SITE SIGNATURES WITH GROUND TRUTH

Ground truth information available to us consists of a large number of
elements including site locations and boundaries, test paddy locations
within sites, planting dates, plant height, stalks per unit area,
harvest dates, plant variety, fertilizer, soil type, soil moisture or
paddy flooding status, and yield. For initial analyses we have chosen
to plot two quantities vs. time for each site: (1) A quantity
indicative of plant growth or chlorophyl showing or, during the harvest
period, indicative of the amount of rice plants still standing at a
given date; and (2) a quantity which represents the soil moisture
status or the percent of flooded paddies within the site. Actually,
the ground truth data for each site consists of information for 6 to
20 paddies which are representative of the entire site (which may
contain 10 times or more that number of paddies).

For plant growth in the IRRI sites (San Nicolas, Malimba, Mahipon) the
plotted quantity is proportional to the products of plant height and
stalks per square meter for the test paddies, and averaged over the

_____

** There is, of course, a much larger area in which rice is grown
   in the vicinity of these sites, but ground truth for the larger
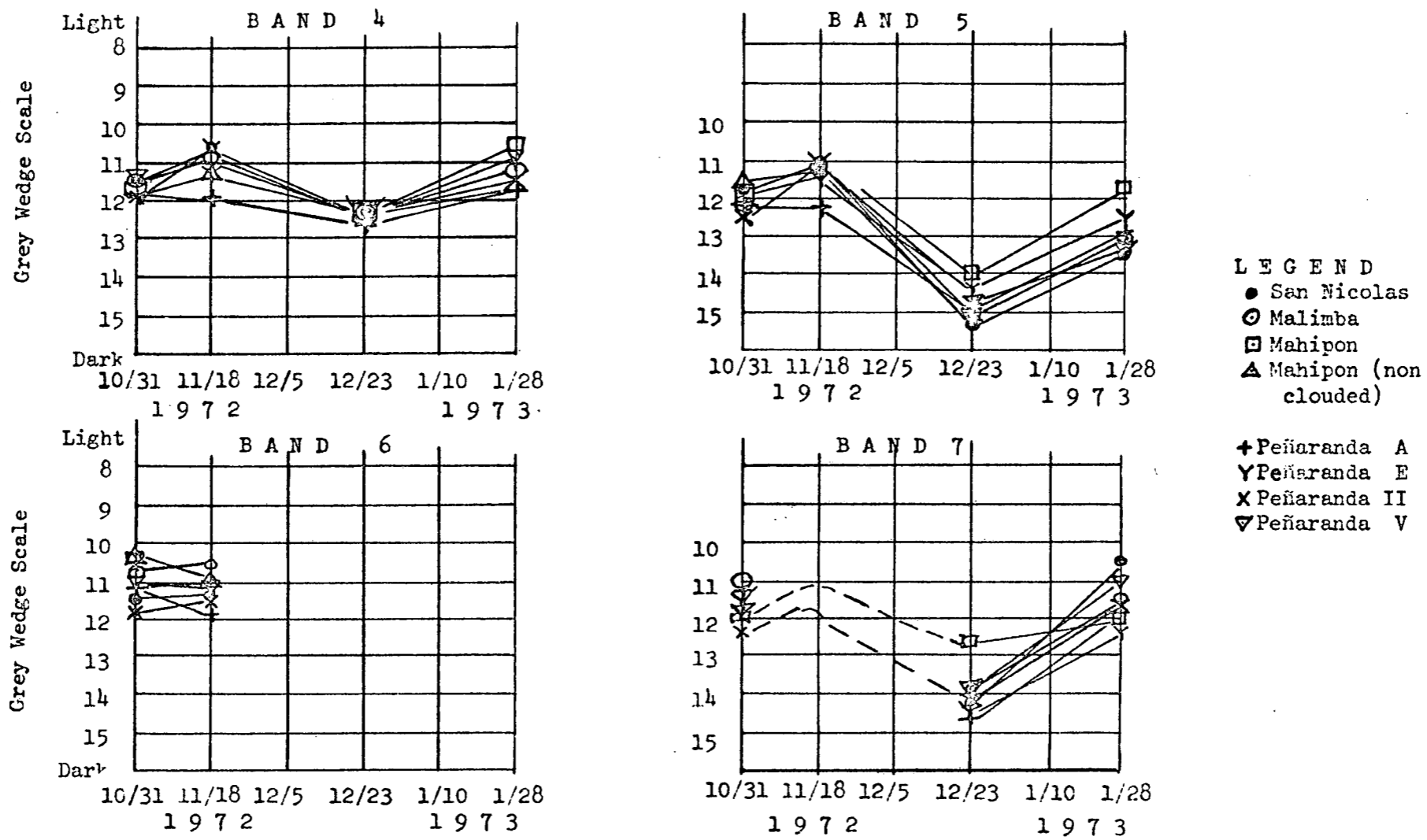   area is not available.

Figure 3. Mean Site Radiation vs. Time

entire site. In the case of the UPLB sites (Peñaranda A, B, II, V), it is proportional to days after planting, since that is the only pertinent information available. Planting dates vary in each paddy, so an average planting date is determined for each full site. Similarly, harvest dates are different for each paddy, and sometimes the total harvest period for a site extends over six weeks. For the harvest period, then, the rice plant plot for a site shows the percent of total paddies where rice is still growing on any given date.
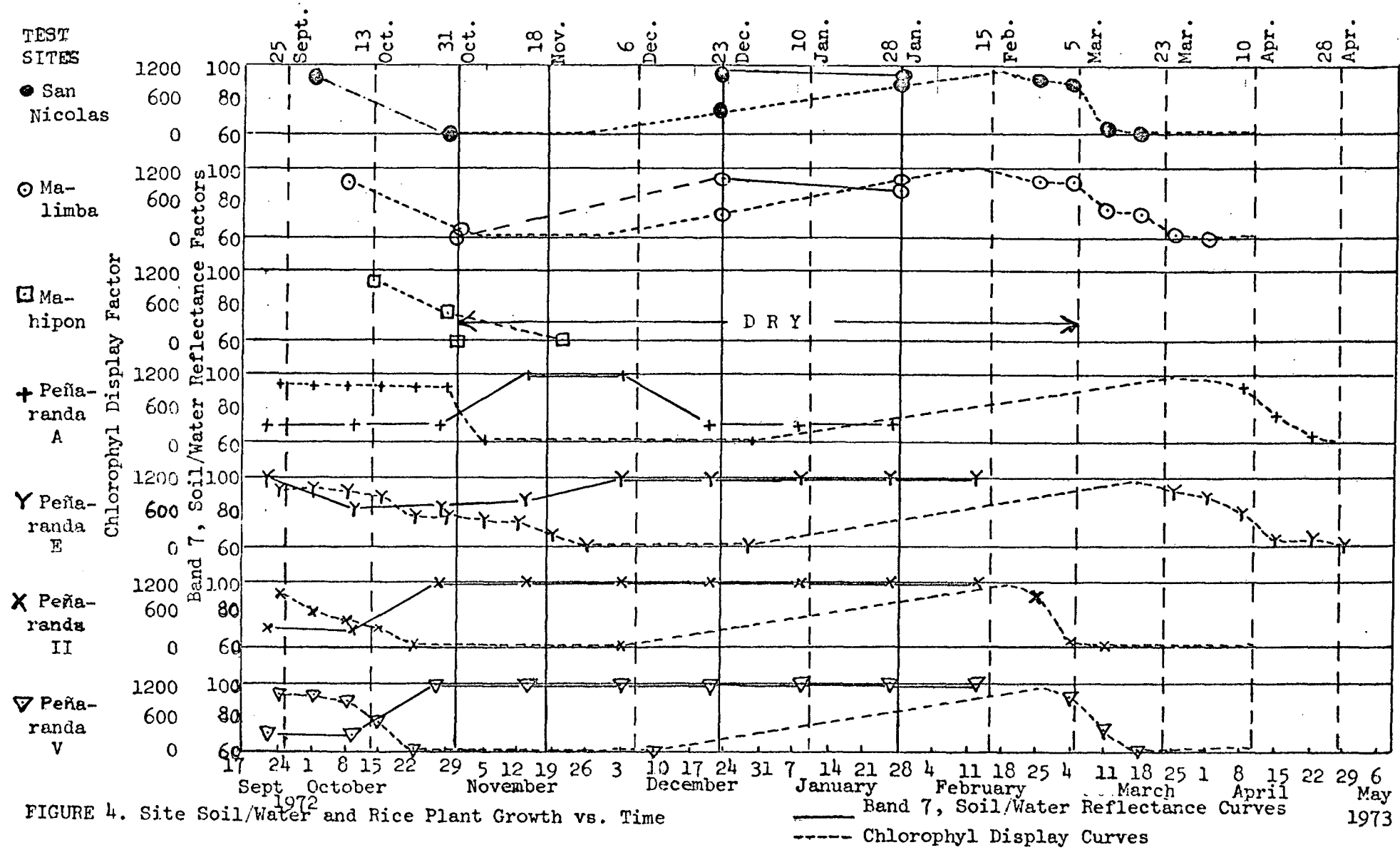
The site water status plots are determined similarly. For the IRRI sites, we have been provided with test paddy information in three discrete categories: Flooded; Saturated; Dry. These conditions have been arbitrarily weighted at 100, 80 and 60, respectively, and an average value for the full site at each sampling date has been computed and plotted. Water status information for the UPLB sites has been supplied to us in the form of "flooded" or "not flooded" for each test paddy. Here, these conditions were weighted arbitrarily at 100 and 70, respectively, and an average value for the full site has been computed and plotted for each sampling date.

The plant growth and water status plots vs. time for each of seven sites, determined as described above, are presented in Figure 4.

We can now compare the plots vs. time of single-band mean radiation intensity for each site with the plots vs. time of site plant growth and water status. First, some general observations can be made. In preparation for a new crop, stubble on the sites may be burned (not always), the paddies are flooded and then plowed. During this period, site responses in all MSS bands can be expected to drop, reaching their lowest values just prior to planting when paddies are flooded but with no plant growth. From planting to a few weeks before harvest, there should be a rise in site response in all bands, particularly in Bands 6 and 7 as the rice plants reflect increasing infrared radiation as they grow. About three weeks prior to harvest, the paddy flooding is stopped and the rice plants become drier. While we yet have no extracted data for confirmation, it is expected that during this period there may be a further rise in the Band 4 and 5 responses and a slight drop in Bands 6 and 7. During harvest a drop in site response in all bands is expected as bare soil becomes exposed. After the harvest is complete, but before preparation for the next crop, there is likely to be a rise in a site response, particularly in Bands 4 and 5, as the bare soil and stubble continue a drying process.

SPECIFIC DATA COMPARISON OBSERVATIONS

1.  For the time period covered, Bands 4 and 5 show about the same information, but differences among sites exhibit a greater spread in Band 5.

2.  Of the seven sites, four were essentially fully harvested by 31 October, and three had an appreciable amount of rice not yet harvested (Mahipon-40%, Peñaranda A-100%, Peñaranda E-50%). By 18 November all but Peñaranda E were essentially 100 percent harvested. Changes in site signatures from 31 October to 18 November were examined. Infrared radiation changes were observed in Band 6 since no Band 7 data for 18 November has yet been extracted. In Band 6 it is noted that for only two sites

FIGURE 4. Site Soil/Water and Rice Plant Growth vs. Time

Band 7, Soil/Water Reflectance Curves

----- Chlorophyl Display Curves

was the radiation appreciably lower in November — Mahipon and Peñaranda A. This is consistent with the site harvest information. (Note that very little harvesting occurred in the Peñaranda E site during the period). Further, it appears that the disappearance of the rice plants at harvest contributes to an appreciable drop in Band 6 radiation over and above any drop due to the appearance of water when a site is flooded after harvest. In the cases here, Mahipon remained dry after harvest while Peñaranda A was harvested and flooded by 18 November.

3. The response in Band 6 for Peñaranda II shows an increase from 31 October to 18 November. This is not yet explainable since that site, according to ground truth information, had been harvested prior to 31 October and was in a flooded condition from 28 October through November. Responses in Band 6 for sites other than Peñaranda II, Mahipon and Peñaranda A changed very little during the period.

4. No conclusions can yet be drawn concerning the absolute and relative values of site responses in Band 6 for 31 October and 18 November, and in Band 7 for 31 October. There are a large number of factors involved here which have not been taken into account.

5. Six of the seven sites show increased radiation in Band 5 from 31 October to 18 November. This remains to be explained as several factors are involved. In at least one case, Mahipon, there is no site flooding after harvest, so the increase probably reflects a drying of the soil and stubble. In other sites where there is flooding after harvest, the stubble may be above the water level and affecting the Band 5 response. But for Peñaranda A still other factors may pertain since there is flooding after harvest but there is no change in Band 5 response from 31 October to 18 November. This lack of change in response is unique for the Peñaranda A site, and the same unique situation occurs in Band 4.

6. The second (dry season, irrigated) rice crop in the 1972-73 year was planted in December, so that ERTS imagery for passes on 23 December and 28 January are useful for analyses of the early growth of this crop. Responses in Band 7 are of particular interest here. It can be noted immediately that on 23 December all sites except Mahipon exhibit a very low and similar response in Band 7. For these six sites this response correlates well with the fact that the six sites are either flooded or saturated and that the new rice crop has been planted for no more than three weeks. In two cases the planting has not yet taken place. The Mahipon site however, is a rainfed barrio and will receive practically no water during the dry season. Therefore, no crop is planted during this season, and the site can be expected to consist of bare soil, perhaps with some stubble and possibly some weeds, becoming drier and lighter in appearance as time goes on. This is borne out by the Band 7 response for Mahipon: brighter than all other sites on 23 December, and increasing in brightness between 23 December and 28 January.

7.  On 28 January it is noted in Band 7 that the responses for all sites except Mahipon have increased to nearly the same as, or greater than, the response for Mahipon. Since the six sites are either 100 percent flooded or nearly so at this time, the conclusion is that the rice plant growth has reached the stage where much of the standing water is masked from satellite view by the plants, or that the infrared reflection from the plants offsets the poor reflection from the water. This correlates well with the fact that rice plant growth in the six sites is four to eight weeks (30-60%) along in the growing period.

8.  An additional observation pertaining to the Band 7 site responses is that these responses on 28 January have increased to about the level which they exhibited on 31 October, harvest time. And, since further plant growth is yet to come, a still higher Band 7 response is expected for the weeks ahead. It is noted also that Band 7 responses at 28 January are beginning to show a spread among the sites. Peñaranda A and E, the sites with the youngest growth (4 weeks), exhibit the lowest responses, as would be expected.

9.  Responses in Band 5 for 28 January appear to support the conclusions reached in the analysis of Band 7 data. That is, the Mahipon site involves bare soil becoming dry, while the other sites contain rice plants with growth beginning to mask portions of the standing water. Increases in radiation in Band 5 from 23 December to 28 January can be expected and are observed for all sites. However, for all sites other than Mahipon the reflected radiation falls below that for Mahipon on both 23 December and 28 January. This correlates on 23 December with an expected higher Band 5 response for bare, drying soil compared to essentially non-vegetated, flooded paddies. Further it correlates on 28 January with an expected higher Band 5 response for still drier bare soil vs. the relatively low "red" reflectance of the rice plants now in growth.

## 3-D SITE SPECTRAL SIGNATURE EXTRACTION

From analysis results to date it appears that it will be desirable, and perhaps essential, to extract from the image data three-spectral-band (i.e., 3-D) site signatures in order to meet program objectives. The spectral radiation is not homogeneous within any site at any time, except possibly if all paddies in a site are flooded at the same time prior to planting. Many of these non-homogeneities, however, contribute in only a small way to the overall site signature. Yet it will be important to detect these differences if useful information is to be extracted for such purposes as yield prediction and as an aid in irrigation management. This must be accomplished in the presence of variability conditions such as different plant varieties in different paddies, different soils and fertilizer treatments and a spread in planting dates for the paddies. Possibly, the 1-D signatures will be adequate for site recognition, but site status assessment is likely to be difficult unless 3-D signatures are employed. This was confirmed in one case in a signature extraction -- signature application experiment. Using GEMS, a 1-D signature was extracted from a Band 7

black-and-white transparency at a site where rice was growing. That signature then was applied to the region containing the remaining sites, with the intent to enhance (as observed on the GEMS TV monitor) those areas where a similar signature existed. Generally, the proper portions of other sites were enhanced, but there was considerable additional enhancement of many site areas where different rice conditions were known to exist. When the process was repeated using a color composite transparency (same sites and satellite pass) and a 3-D signature extraction, the resulting enhancement was of a finer grain and more precisely and accurately located.

As of 15 August 1973 only two color composite transparencies have been available, those for passes over the sites on 31 October and 18 November. Results in these two cases using 3-D signatures appear promising, but tests with additional frames are necessary, of course.

A radiometric calibration is performed, similar to the 1-D case, in which the 32 GEMS-measured intensity levels in each of three bands are related to the steps in the 15-step gray wedge in the color composite transparency. In an attempt to keep signatures as simple as possible yet sufficiently detailed to do the job, the 32 GEMS-measured intensity levels in each of three bands were combined so as to produce only five larger increments of six GEMS levels each. Usually this consisted of GEMS levels 3-8 for the first increment, levels 9-14 for the second increment, etc. The result is a 5 X 5 X 5 = 125-cell 3-D color space, which is illustrated in Figure 5. An extracted 3-D signature in this system consists of the percent of total pixels for the scene area of interest which fall within each of the 125 color cells. Each color cell is designated by its quantized location along the three spectral axes, with larger numbers referring to a higher radiation level in that channel. For example, cell 1-3-5 corresponds to radiation which is simultaneously at the lowest level in channel 1, at the middle level in channel 2, and at the brightest level in channel 3. In our system, channel 1 pertains to "green" in the transparency, channel 2 to "blue" and channel 3 to "red". In turn, these channels pertain to the MSS spectral bands in accordance with the preparation of the color composite -- usually blue for MSS Band 4, green for Band 5 and red for Band 7. Figure 5 shows the location of cell 4-4-3.

3-D site histogram signatures are extracted in a manner similar to that for 1-D signature extraction. The binary site map is recalled from store and registered visually with the color transparency. Using the GEMS cursor to define which site in the site map is of interest, that designated portion of the site map is used to gate out a 3-D signature which is recorded on tape and subsequently printed out by the GEMS computer. 3-D histogram extraction has been performed for:

    (1)   The same site and same frame, but on different analysis days

    (2)   Different sites, but the same frame, and on the same and different analysis days

    (3)   The same site, but two different frames (two satellite passes).
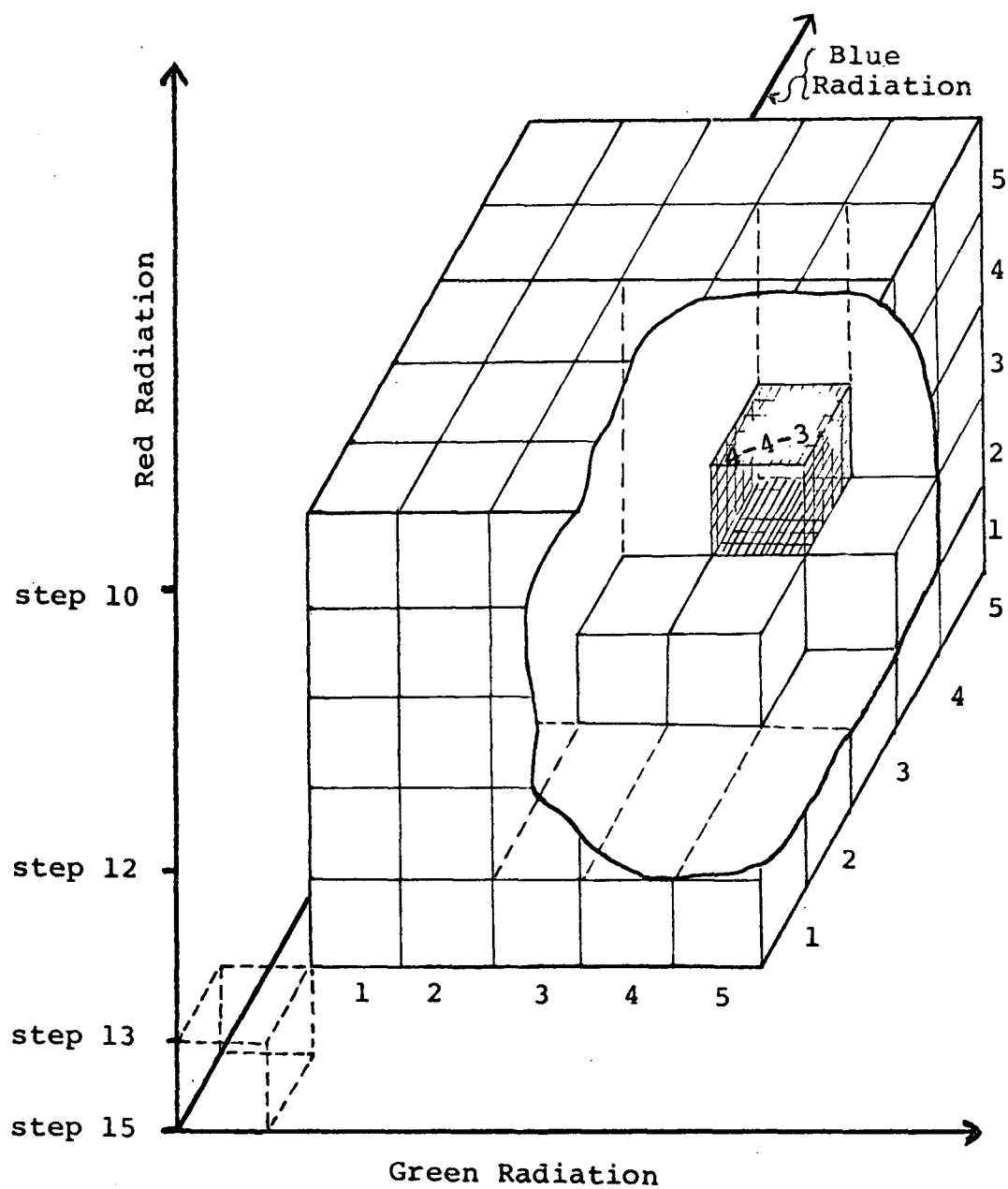
FIGURE 5. 125 Cell 3-D Color Space

Results to date from (1) and (2) indicate that 3-D histograms are repeatable to an acceptable degree and that there are detectable differences in the 3-D signatures for different sites (where different conditions prevail). Results from (3), although limited because only two frames have so far been available, indicate that a number of changes in site conditions between two dates are detectable via the 3-D signatures extracted from the different frames. This will be described further in the section which follows. An illustration of a portion of the results for (1), (2) and (3) above is given in Figure 6.

As another check on the 3-D histogram signatures, 3-D signatures for three sites in one frame were converted to three sets of three 1-D signatures. These compared favorably (within a half-step) with the 1-D signatures for the same sites and frame which were extracted from the black-and-white single-band transparencies.

### SYNTHESIS OF 3-D SITE FEATURE SIGNATURES

It was mentioned previously that at most times the sites are spectrally non-homogeneous due to varying conditions from paddy to paddy within each site. At the present time we have not sub-divided the ground truth information to show where different paddy conditions are located within the overall site. This will be done in the future. However, in some cases it may be difficult to correlate these conditions with extracted signature data because of the extreme difficulty in locating in the imagery precisely where the conditions occur. Position accuracies in the order of two ERTS resolution cells can be involved.

In spite of the above situation, an initial approach has been made toward synthesizing 3-D signatures for features (i.e., conditions) within a site, as opposed to a signature for an overall site. This was done as follows. The color composite for 31 October was used in GEMS, and a zoomed portion encompassing the test site region was displayed in color on the GEMS TV monitor in essentially the same colors as exist in the transparency. Upon study of the monitor display it became apparent that seven frequently occurring colors could be distinguished visually: Dark blue, blue, bluish pink, dark red, red, pink and light beige. (White, such as in clouds, and black, such as in ocean water or cloud shadows, also are distinguishable, of course). These seven colors will change with adjustments in the color display or with a different color composite preparation, but seven distinguishable colors will still exist except in extreme cases.

Further study of the color display in conjunction with ground truth information led to an estimated association of each color with a certain scene condition. This association, listed below, remains to be fully verified, but is believed to be a satisfactory first approximation:
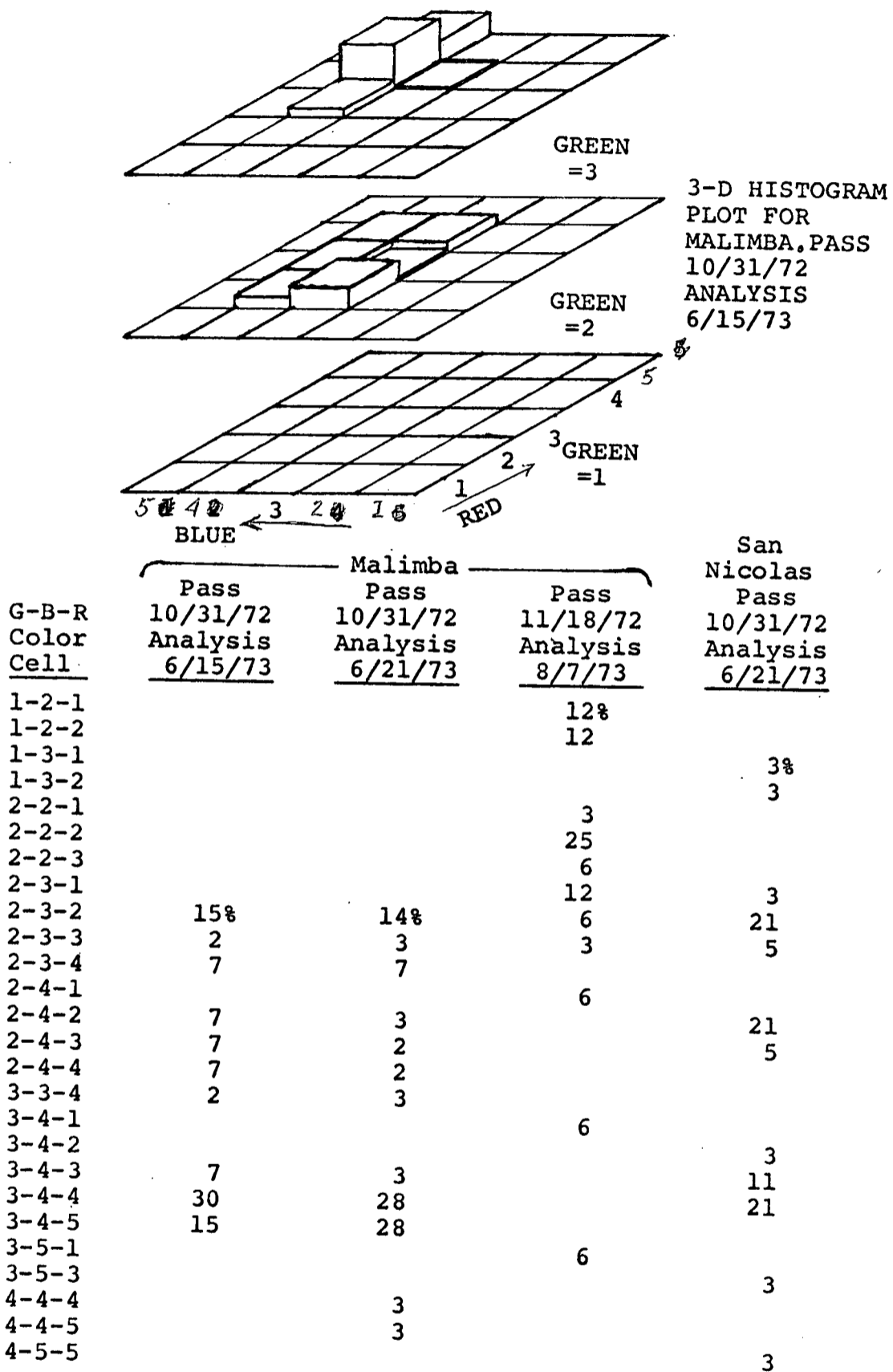
B

3-D HISTOGRAM PLOT FOR MALIMBA,PASS 10/31/72 ANALYSIS 6/15/73

GREEN =3

GREEN =2

GREEN =1

RED

BLUE

| G-B-R Color Cell | Malimba Pass 10/31/72 Analysis 6/15/73 | Malimba Pass 10/31/72 Analysis 6/21/73 | Pass 11/18/72 Analysis 8/7/73 | San Nicolas Pass 10/31/72 Analysis 6/21/73 |
|---|---|---|---|---|
| 1-2-1 | | | 12% | |
| 1-2-2 | | | 12 | |
| 1-3-1 | | | | 3% |
| 1-3-2 | | | | 3 |
| 2-2-1 | | | 3 | |
| 2-2-2 | | | 25 | |
| 2-2-3 | | | 6 | |
| 2-3-1 | | | 12 | |
| 2-3-2 | 15% | 14% | 6 | 3 |
| 2-3-3 | 2 | 3 | 3 | 21 |
| 2-3-4 | 7 | 7 | | 5 |
| 2-4-1 | | | 6 | |
| 2-4-2 | 7 | 3 | | 21 |
| 2-4-3 | 7 | 2 | | 5 |
| 2-4-4 | 7 | 2 | | |
| 3-3-4 | 2 | 3 | | |
| 3-4-1 | | | 6 | |
| 3-4-2 | | | | 3 |
| 3-4-3 | 7 | 3 | | 11 |
| 3-4-4 | 30 | 28 | | 21 |
| 3-4-5 | 15 | 28 | | |
| 3-5-1 | | | 6 | |
| 3-5-3 | | | | 3 |
| 4-4-4 | | 3 | | |
| 4-4-5 | | 3 | | |
| 4-5-5 | | | | 3 |

FIGURE 6.   3-D HISTOGRAM DATA

14

| Color in the Color Composite for MSS Bands 4, 5, 7 | Scene Feature in Rice Region (Rice Field Condition) |
|---|---|
| Dark Blue | – Layer of water over bare soil, or saturated bare soil |
| Blue | – Moist, bare soil |
| Bluish Pink | – Moist, bare soil with rice stubble or weeds |
| Dark Red | – Growing rice, with some standing water or saturated soil visible |
| Red | – Growing rice – no moisture stress |
| Pink | – Growing rice – nearing maturity |
| Light Beige | – Growing rice – drier |

Next, the GEMS cursor was placed successively over small areas in the displayed image where each of the seven colors appeared to exist homogeneously. 3-D signatures were then extracted, and the results were used to identify which of the 125 color cells in the 5 X 5 X 5 color space corresponded to each of the seven colors in the color composite transparency. For example, "Dark Red" involves color cells 1-1-2, 1-2-2, 1-2-3, and 1-3-3. Actually, the color cell identification process was an iterative one, using only the color composite for 31 October and gradually taking site ground truth information for 31 October into account. Eventually, about one-third of the 125 color cells were labeled in this manner.

Finally, the 3-D histogram site signatures for the seven sites on 31 October and 18 November were matched against the labeled color-space cells. If the site signature showed 20 percent of the total pixels for the site fell within color cells 1-1-2, 1-2-2, 1-2-3, and 1-3-3, then 20 percent of the site was considered to be "dark red" or involving "growing rice with some water visible". The composition of each of the seven sites was thus specified in percentages of each of the seven described (estimated) rice field conditions. This was done for the 31 October and the 18 November color composite imagery. Results are presented in Figure 7. It is important to note, however, that the training (color cell labeling, or synthesis of rice field feature signatures) was accomplished using only the 31 October imagery. The synthesized feature signatures were applied to the 31 October image data as a check on the synthesis, and to the 18 November image data for an initial look at the adequacy of that synthesis.
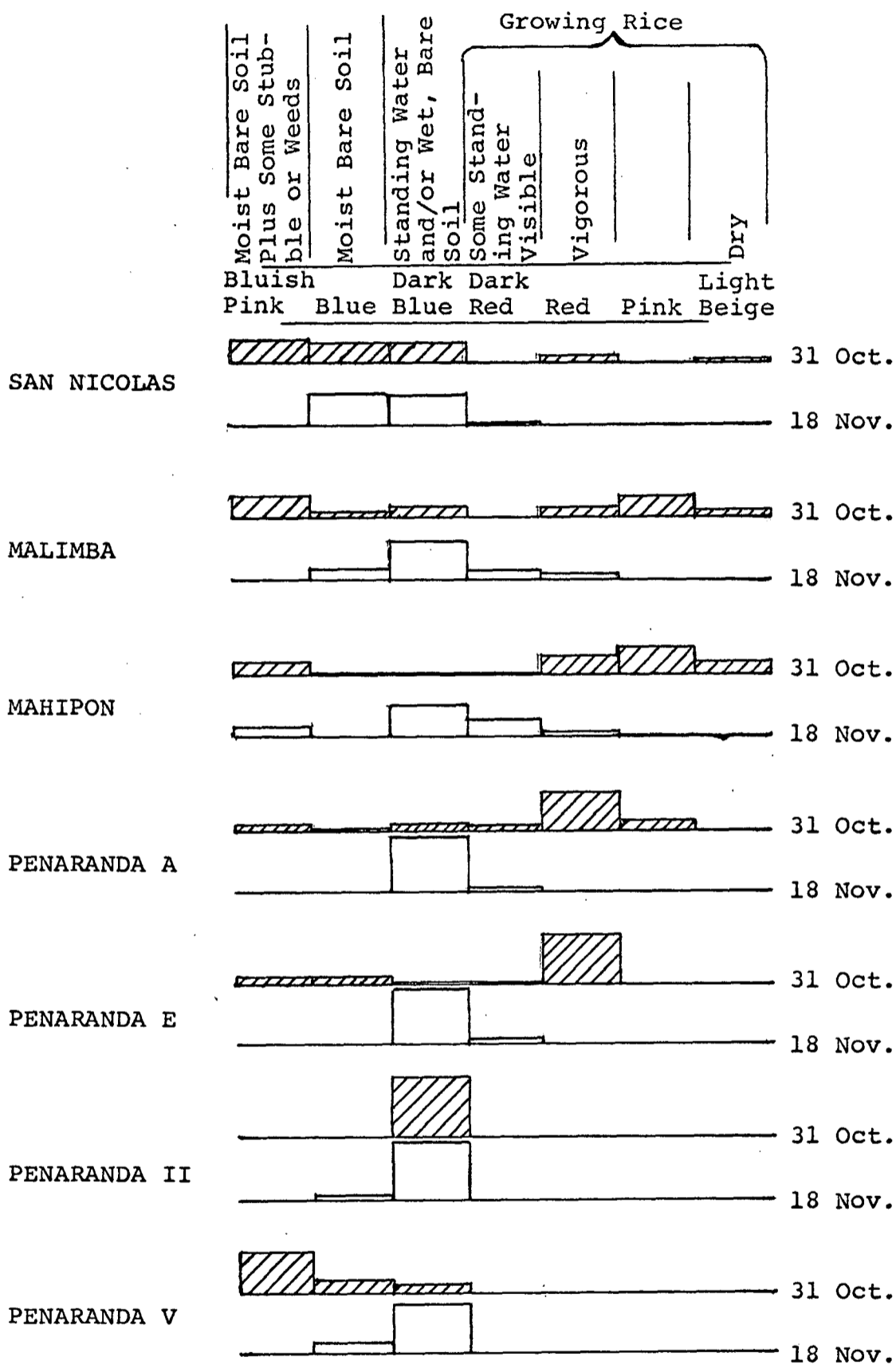
Growing Rice

Moist Bare Soil Plus Some Stub-
ble or Weeds

Moist Bare Soil

Standing Water and/or Wet, Bare Soil

Some Stand-
ing Water Visible

Vigorous

Dry

Bluish
Pink

Dark
Blue

Dark
Red

Blue Red Pink

Light
Beige

SAN NICOLAS — 31 Oct.
— 18 Nov.

MALIMBA — 31 Oct.
— 18 Nov.

MAHIPON — 31 Oct.
— 18 Nov.

PENARANDA A — 31 Oct.
— 18 Nov.

PENARANDA E — 31 Oct.
— 18 Nov.

PENARANDA II — 31 Oct.
— 18 Nov.

PENARANDA V — 31 Oct.
— 18 Nov.

FIGURE 7.  EXTRACTED SITE COMPOSITION
FROM
3-D FEATURE SIGNATURES AND SITE HISTOGRAMS

16

## COMPARISON OF EXTRACTED SITE COMPOSITION (FROM 3-D) SIGNATURES WITH GROUND TRUTH

The comparison here will be brief since the synthesized rice-field feature signatures have only been applied to imagery for two satellite passes, the first of which was used for training.

Referring to Figure 7 it is noted that on 31 October the only sites where the extracted data indicates rice is growing (red colors, and light beige) in any significant amount are Malimba, Mahipon, Peñaranda A and Peñaranda E. This corresponds to the ground truth situation. Of these four sites, Malimba has the greatest percentage of harvested area, and there is good correlation concerning this. The extracted data show San Nicolas and Peñaranda II and V as containing essentially all bare soil (with varying degrees of moisture, stubble or weeds). This, too, checks with ground truth information which shows these sites as recently 100-percent harvested.

For 18 November, the extracted data show San Nicolas and Peñaranda II and V as continuing to be composed of nearly 100-percent bare soil (harvested). Peñaranda A also is indicated as falling in this category. These situations are confirmed by ground truth. The correlation of extracted data with ground truth for Malimba, Mahipon and Peñaranda E, however, is fairly good but does involve some situations which are not yet explainable. Malimba should be fully harvested, but the extracted data indicates 22% of the site still contains growing rice. Mahipon presumably has only 5% unharvested rice remaining, but extracted data indicate 40%. Finally, Peñaranda E should have about 25% unharvested rice remaining, but extracted data indicates this figure is 5%.

These first-cut results are encouraging, but a refinement of the rice-field feature signatures and a re-check of ground truth data is indicated. And, of course, the feature signatures need to be tested and refined using imagery for additional passes over the sites.

There is evidence that the feature signatures can be refined as desired. For example, the 3-D site histogram signatures for Peñaranda A and E for 31 October and 18 November were re-examined. Histograms for both sites showed, as expected, a shift to the darker color cells from 31 October to 18 November, but Peñaranda E appeared to have the greater percent pixel population in color cells in the vicinity of those now labeled as "red". Thus, a further iteration of the rice-field feature signature synthesis (a refinement in the labeling of the 3-D color cells) could well result in a more accurate indication from extracted data of the percent unharvested rice in the Peñaranda E site on 18 November.

## SUMMARY AND PROJECTION

One of the goals in the overall investigation is to arrive at a basis
for recognition in the image data of areas where rice is grown, and
temporal patterns of spectral signatures are a key element in the
approach. In proceeding toward the goal, the correlation with ground
truth of extracted 1-D site signatures, and the correlation with ground
truth of initial 3-D algorithms for the recognition of site composition,
have been encouraging, although some inconsistencies in the correlation
remain to be resolved. It is necessary to extend the image data
analysis through full wet and dry season growing cycles, and to
include more diversity in the test sites which are analyzed.

A rice field recognition-process using satellite imagery for the
entire Philippines may not have to be a fully automatic process. It
would consist of a heavy initial effort plus a small periodic updating
activity. (Changes in rice-field boundaries, or the conversion of a
rice field to another use, are infrequent). 1-D signatures, plus good
position location procedures, may be adequate for the rice field
recognition.

Rice field status assessment using satellite imagery involves
accounting for many complex factors. Further, in an operational
situation, the assessment must be performed periodically and rapidly,
if results are to be useful for irrigation management, yield prediction
and similar functions. This essentially dictates a heavily automated
assessment procedure, very likely based on the use of 3-D signature
data. For reasons previously described, image data in the form of
color and black-and-white transparencies are employed in the present
analysis. But an operational procedure very likely would be based on
the use of digital image data on tape.

## ACKNOWLEDGMENT